

Creating Superior Electroluminescent Backlighting with Mixture Design

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Handheld electronic devices featuring brightly glowing keypads have achieved wide acceptance by design engineers in recent months. This is primarily because of carefully engineered ~0.1mm flexible electroluminescent (EL) lamps. These evenly backlit keypad numbers, letters, and other characters create a fresh and uniform look.

Until only recently, light emitting diodes (LEDs) provided uneven light across the keypad, resulting in some characters being too bright while others were barely visible. New-product designers had been demanding thinner, whiter, and more-uniform illumination than the old technology was able to provide. To meet these requirements, Rogers' R&D engineers began conducting mixture-design experiments. The search was on for a white backlight lamp having maximum luminance and color coordinates of $x = 0.31 \pm 0.02$ and $y = 0.35 \pm 0.02$ per the C.I.E 1931 Chromaticity Diagram.

The natural EL lamp color is green, with color coordinates of $x = 0.17$ and $y = 0.44$. To convert this green light into a white light, using mixture design, engineers discovered an ideal pigment combination. By printing an added color layer onto the green lamp, light passing through it converts into the sought-after white light. The result is a white lamp that fully meets market requirements. Recently transferred into high-volume production, the new lamp is now known as DFLX™ - DUREL Flexible Electroluminescent Lamp.

MIXTURE DESIGN PROTOCOL

To begin hunting for the designer-preferred white backlight, engineers selected three pigments considered the most likely candidates for shifting the light spectrum. Selecting the right pigments was relatively easy after reviewing historical data. The truly difficult task, however, was to determine the proper pigment ratios needed to produce the required color coordinates. To find these ratios, we used DOE (design of experiments) software to create a three-component pigment model. Mixture designs are ideal when combining two or more components, particularly when the responses

are a function of proportions rather than amounts. Furthermore, mixture design addresses the fixed total in a mixture. That is, when the percentage of one component is changed, it automatically changes the percentage of the other components.

To protect Rogers Corporation’s proprietary data, the three pigments we used are masked in this article:

- Component 1 Pigment A
- Component 2 Pigment B
- Component 3 Pigment C.

The responses are labeled:

- Luminance (fL)
- x-Color Coordinate
- y-Color Coordinate.

We set our DOE software (Design-Expert® software, Stat-Ease, Inc.) to perform a D-optimal design. This design chooses the minimal number of blends ideally formulated to predict responses. In this case, Design-Expert laid out a “recipe sheet” with 14 blends, of which four were replicates for estimation of error.

Constraints (upper and lower boundaries for each individual pigment, and the total boundary for all three combined pigments) were as follows:

- Each of the three pigments must range from 0 to 7 units
- All three pigments must sum to nine units: $A + B + C = 9$.

Table 1 defines the goals in detail.

TABLE 1. CONSTRAINTS, BOUNDARIES, AND GOALS DEFINED—Each of the three pigment components falls within 0-7 units. Luminance is maximized when it is greater than ten foot-Lamberts. Below 10 units has no desirability and 11 represents a completely desirable result. X- and y-Color ranges must fall within C.I.E 1931 Chromaticity Diagram goals of $x = 0.31 \pm 0.2$ and $y = 0.35 \pm 0.2$. (Table courtesy of Rogers Corporation.)

NAME	GOAL	LOWER THRESHOLD	UPPER THRESHOLD
Luminance	Maximize	10	11
x-Color	Is in range	0.29	0.33
y-Color	Is in range	0.33	0.37

The Design-Expert DOE software screenshot in Figure 1 shows the mixture-design layout we followed during experimentation.

Id	Run	Block	Component 1 A:Pigm. A %	Component 2 B:Pigm. B %	Component 3 C:Pigm. C %	Response 1 Luminance fL	Response 2 x Color ratio	Response 3 y Color ratio
1	7	Block 1	7.00	2.00	0.00	10.075	0.3164	0.3551
1	12	Block 1	7.00	2.00	0.00	9.968	0.3201	0.3558
2	5	Block 1	0.00	2.00	7.00	9.074	0.2694	0.2933
2	10	Block 1	0.00	2.00	7.00	9.022	0.2733	0.2917
3	1	Block 1	0.00	7.00	2.00	9.915	0.2892	0.3171
3	6	Block 1	0.00	7.00	2.00	9.179	0.2911	0.3158
4	11	Block 1	4.50	0.00	4.50	9.656	0.303	0.3294
5	8	Block 1	2.00	7.00	0.00	9.649	0.3059	0.3342
6	2	Block 1	3.00	3.00	3.00	10.086	0.2943	0.3276
6	13	Block 1	3.00	3.00	3.00	9.53	0.2965	0.3279
7	4	Block 1	0.00	4.50	4.50	9.475	0.2793	0.3051
8	3	Block 1	4.50	4.50	0.00	9.933	0.3122	0.3459
9	9	Block 1	7.00	0.00	2.00	9.918	0.3183	0.3497
10	14	Block 1	2.00	0.00	7.00	10.183	0.2775	0.2956

FIGURE 1. MIXTURE-DESIGN LAYOUT—Combinations (runs) show pigment quantities and responses generated for each of the 14 D-optimal design blends. Note that the “Run” column shows the randomized order in which runs were conducted. (Screenshot courtesy of Stat-Ease, Inc.)

DESIGNERS, CAN YOU SEE ME NOW?

The DOE software discovered four solutions in which all goals were satisfied, but the composition listed as #1 (Table 2) is the most desirable for luminance.

TABLE 2. BACKLIGHT LAMP SOLUTIONS—DOE software chooses solution #1 (yellow) as the best. The solution meets all constraint and goal specifications, and ranks highest in desirability. (Table courtesy of Rogers Corporation.)

No.	PIGM. A	PIGM. B	PIGM. C	LUMINANCE	x-COLOR	y-COLOR
1	6.87	2.07	0.06	10.07	0.321	0.356
2	7.00	1.84	0.16	10.07	0.321	0.356
3	7.00	1.53	0.47	10.06	0.320	0.355
4	7.00	0.25	1.75	10.04	0.315	0.350

Figure 2 shows three contour graphs in which predicted responses for luminance, x-Color, and y-Color are identified as a function of the mixture components (pigments A, B, and C.) Each contour line within a triangle represents a constant response, as shown in respective labels in the white boxes. Each blend appears as a red dot, with non-decimal numbers next to some dots indicating the number of replicates at that set of conditions. For example, the “2” located at the center point on the right ternary plot in Figure 2 means that we reproduced these same conditions at two random instances during the experiment.

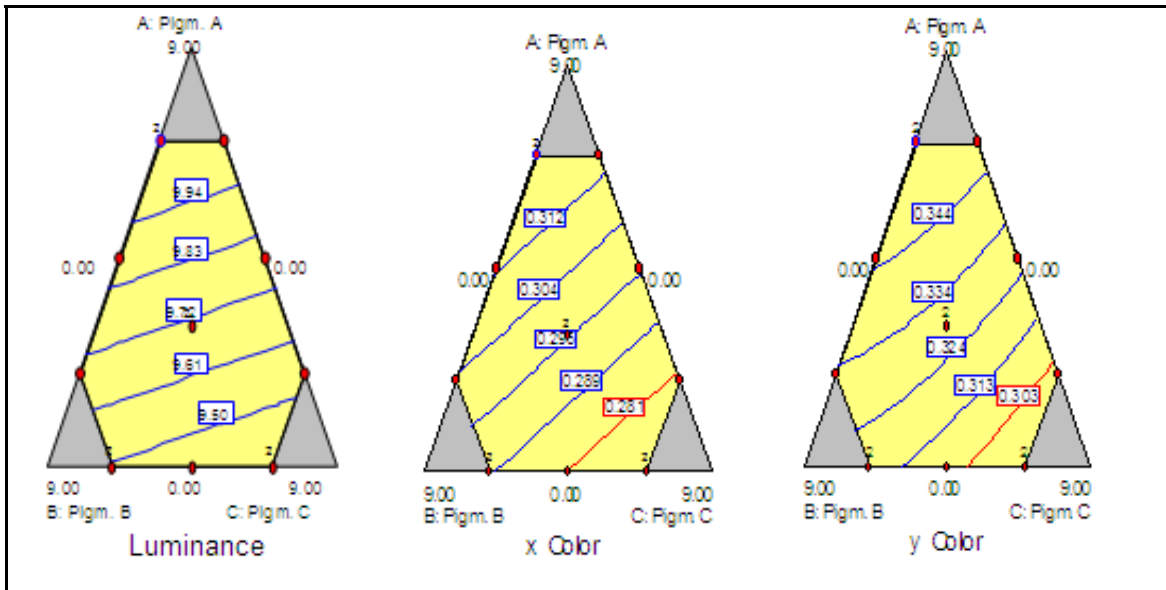


FIGURE 2. THREE PREDICTED RESPONSES—For each predicted response (luminance, x-Color, and y-Color), pigments A, B, and C originate as zero (the lower constraint) at a triangle’s side. That side’s vertex, opposite its zero origination point, is the three components’ summed upper constraint (nine for this DOE). (Screenshot montage courtesy of Stat-Ease, Inc.)

MIXTURE DESIGNS—WINDOWS OF OPPORTUNITY

To find where all specifications meet, the DOE software automatically superimposes the three plots graphed in Figure 2, revealing an open “sweet spot” in Figure 3. The boxed-in results atop the Design-Expert overlay plot indicate the ideal mixture-design’s predicted pigment ratios to be:

- Pigment A = 6.87 units
- Pigment B = 2.07 units
- Pigment C = 0.06 units.

Follow-up confirmation runs verified these ratios. Product designers who were given lamp prototypes declared the new electroluminescent backlights a success.

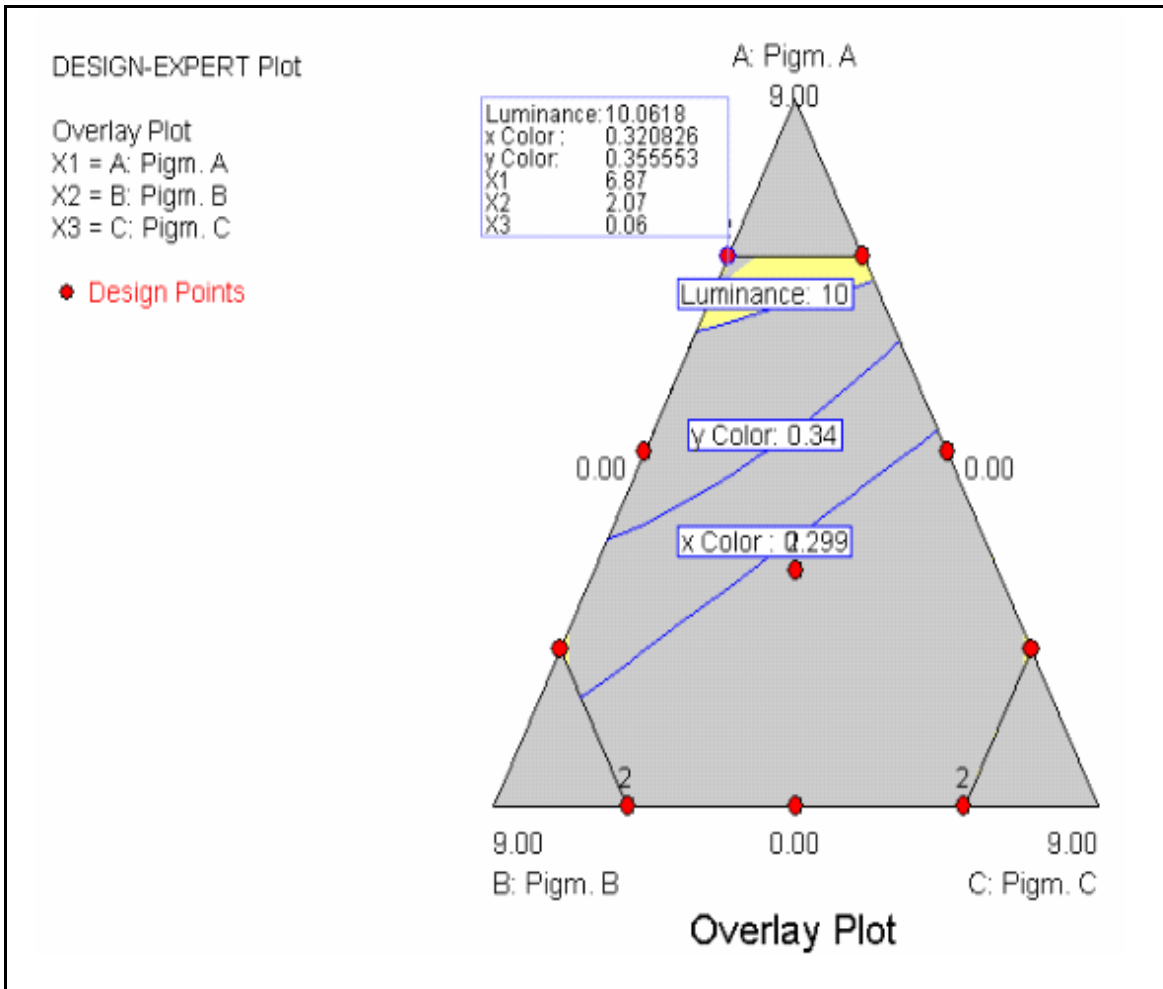


FIGURE 3. OVERLAY PLOT—The three plots from Figure 2 are superimposed upon one another, revealing an open “sweet spot” (composition X1=6.87, X2=2.07, X3=0.06) where all performance criteria meet. (Screenshot courtesy of Stat-Ease, Inc.)

Mixture design is an extremely effective approach for optimizing formulations. Powerful optimization routines within Design-Expert DOE software reveal “sweet spots” showing those oftentimes narrow windows of opportunity. By “shading out” areas beyond specification, software graphs clearly display the most desirable component mixture. Although our mixture designs are bounded by constraints, because of our experimentation, our product designers now have fewer constraints and more latitude.

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